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RIGID POLYURETHANE FOAM - COMPRESSIVE STRENGTH VARIATION WITH DENSITY AND TEMPERATURE

Report No. 89-148-K

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ABSTRACT

Compression tests of flat circular foam samples were undertaken to explore the dependency of polyurethane foam crush strength on temperature and density. Sample density varied from 200 to 350 kg/m³ and specimens were tested at temperatures from -40°C to +40°C. Crush strength was found to be inversely proportional to temperature with a 50% change over this temperature range.

A large variation in foam density (up to 38%) was found between samples of the same nominal density. An understanding of the causes of this variation should be sought. Methods of ensuring foam consistency should be instituted to guarantee predictable and adequate material properties.

A numerical relationship which predicts average crush strength from foam density and temperature input was developed from the experimental data. This can be used to predict the effect of ambient temperature changes on a foam of known crush strength.

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To Mr. D.W. Souther
Manager - Nuclear Engineering Department
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RIGID POLYURETHANE FOAM - COMPRESSIVE STRENGTH VARIATION WITH DENSITY AND TEMPERATURE

1.0 INTRODUCTION

Rigid polyurethane foam is currently in use as an impact absorbing material in several containers licensed for the transport of radioactive materials. It has been used as the main constituent of removable overpacks (impact limiters) and as an integral part of the structure (D₂O transport flask). A full understanding of the energy absorbing behaviour of this material over the temperature range where it is expected to function is of great interest to designers of such containers.

This report describes the results of a series of simple compression tests. These were undertaken to quantify the variation in crush strength due to foam density and temperature changes.

2.0 DESCRIPTION OF TEST

Unconstrained disks (100 mm diameter, 25 mm thick) were compressed between parallel platens. All samples were compressed with the same strain rate to approximately 75 % strain. A load vs displacement curve was generated for each sample; these appear in Appendix B, Experimental Data.

A total of 60 samples was tested according to the test matrix shown in Table 1. Two samples of each density were tested at each of five test temperatures: -40°C, -20°C, 0°C, 20°C and 40°C.

2.1 Test Samples

A local supplier (WITCO Canada Inc.) was asked to supply 100 mm diameter cylinders of foam in the following densities : 14, 16, 18, 20, 22 and 24 lb/ft³. Cylinders were poured in a series of layers, each approximately 25 mm thick. The surface of each cylinder was machined to remove surface film and irregularities, then 25 mm thick disks were cut.

Specimen aspect ratio is defined as: loaded area divided by the surface area free to expand. It was concluded in an earlier study of unconstrained foam that the aspect ratio of specimens affected their crush response. This effect was not significant in samples with aspect ratios greater than 0.75./1/. Samples tested in the current study had a nominal aspect ratio of 0.95.

2.2 Test Method and Apparatus

Room temperature testing (20°C) was conducted on a 600,000 lb Baldwin Universal Test machine, see Figure 1. Results from these tests indicated that the maximum load required was less than originally anticipated. All other tests were conducted on a 120,000 lb universal test machine inside an environmental chamber. The stiffness of each experimental apparatus was tested and is shown in Figures B.1 and B.2, Appendix B.

Load was applied such that samples reached 65% strain in 1 minute. This rate was chosen since earlier work suggests this foam is relatively insensitive to strain rate at rates this order of magnitude/2/.

Strain was derived by monitoring crosshead displacement and compensating for the stiffness of the test system. This avoided the difficulties inherent in calibrating and operating an extensometer inside the environmental chamber. Load was measured with an internal load cell.

Tests at -40°C, -20°C, 0°C and 40°C were conducted in an environmental chamber, see Figures 2, 3 and 4. To ensure thermal equilibrium, samples were held at temperature for a minimum of 6 hours prior to testing. After positioning the sample (which required less than one minute), the environmental chamber was closed and allowed to return to the appropriate test temperature. The sample was then held at temperature for a minimum of 10 minutes before being compression tested.

3.0 RESULTS

A 40% strain level was chosen as a reference point for comparison of results between different densities and temperatures. This point reflects an average crush strength for the foam, see Figures B-5 to B-9 (load displacement curves), Appendix B.

3.1 Variation in Crush Strength - Data Analysis

Test apparatus compliance and any initial space between platen and specimen were subtracted from the recorded strain to give true sample strain. Test data such as: density, area of the loaded face, load at 40% strain, calculated crush strength and test temperature are shown for all samples in Table 2.

Crush strength is plotted against density for each test temperature in Figure 5. In this figure, foam crush strength at a given temperature appears to be directly dependent on density. Linear regression was used to calculate a best fit line for data at each temperature. Since the slope of these lines varies, it is apparent that temperature change causes an additional variation in crush strength. In low density foams (200 kg/m³), crush strength increased by 45% as the temperature drops from 20°C to -40°C, conversely it decreased by 6% as temperature increases by 20° to 40°C.

In high density foams (350 kg/m³), a slightly different effect is seen. A decrease in the temperature from 20°C to -40°C increased the crush strength by 35%. Increasing temperature from 20° to 40°C reduced crush strength by about 15%.

3.2 Foam Density Prediction - Quality Assurance

Since the compressive strength of this foam is directly related to its density, ability to predict foam density translates directly into the ability to predict compressive strength.

The manufacturers' predicted density, average density and variation in the samples are tabulated in Table 3. With the lower density foams, actual densities are somewhat greater than values indicated by the manufacturer (4 to 8%). In high density foams, actual densities are significantly lower (approximately 18% less) than that indicated by the manufacturer. This high variability may be partially due to the shape and small size of the material samples requested.

There was also a large variation in the density of samples machined from the same cylinder, it varied up to 38% in the more dense samples. In an earlier study, 6 samples with an average density of 312 kg/m³ and similar in geometry to our samples exhibited a maximum variation in density of 7%/2/

3.4 Numerical Model of Crush Strength

In order make use of the data gathered in this series of tests, a numerical model was developed from the experimental results. Equation 1 estimates the 40% crush strength of polyurethane foam from temperature and density input. Appendix A describes the development of this equation.

$$S_{\text{crush}} = (-2.5155 \times 10^{-4} \times T \pm 0.13322) \times R_o + (4.8394 \times 10^{-4} \times T^2 - 0.2486 \times T + 23.0515) \quad (1)$$

S_{crush} = crush strength at 40% strain (MPa)

T = temperature (degrees K)

R_o = density (kg/m³)

This equation reproduces test data to within approximately 10% error for the lowest density foams. For foam densities greater than 250 kg/m³, it predicts crush strength to within 2%. Thus it can be used to predict the effect of temperature on a foam of known crush strength.

3.5 Strain Recovery

Figures 6 and 7 show the amount of permanent set in samples with the same nominal density. Foam tested at below 0°C was considerably more resilient. It recovered over several minutes and had a permanent strain of approximately 35%. Samples tested at room temperature and +40°C experienced a permanent set of approximately 55%.

4.0 CONCLUSIONS

- 1) Temperature change caused a 50% variation in the crush strength of rigid polyurethane foam over the temperature range tested. Crush strength varied inversely with temperature.
- 2) The average density of foam deviated by up to 18% from the manufacturer's estimate. This impacts directly on the foams' anticipated crush strength. A method of ensuring predictable material properties of all foam used in radioactive packaging must be

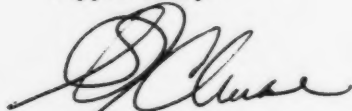
implemented to be certain of acceptable material properties. This may take the form of developing a reliable foam fabrication procedure or defining appropriate tests to be performed.

- 3) Variation in density between samples from the same cylinder (up to 38%) indicates a possible presence of soft spots. An understanding of the cause of this should be sought and any ramifications of this should be fully evaluated with respect to existing and future designs.
- 4) A relationship has been developed that will predict average crush strength across the temperature range -40°C to $+40^{\circ}\text{C}$ for foam densities from 200 to 350 kg/m^3 .
- 5) When cold (below 0°C), foam is more elastic and has less permanent deformation than when it is warm ($\geq 20^{\circ}\text{C}$).

5.0 ACKNOWLEDGMENTS

All testing and recording of experimental data was performed by Mr. D. Austin, Mechanical Testing Section. The author gratefully acknowledges his contribution to this report. This work was performed for and funded by the Nuclear Material Management Department.

Approved by:



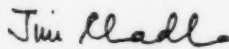
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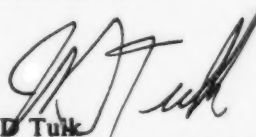
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REFERENCES

1. D.A. Black, "Mechanical Properties of Polyurethane Foam for Tritiated Heavy Water Transportation Package". Ontario Hydro Research Research Division Report No. B84-79-H, November 1984.
2. N.N. Shah, "Measurement of Compressive Properties for Polyurethane Foam", Ontario Hydro Research Division Report No. B87-50-K, File 825.94, September 3, 1987.

TABLE 1

Test Matrix

All temperature and density combinations shown in this matrix were tested, a stress-strain curve was generated for each sample.

Notes at the bottom of table explain the sample identification system used during testing.

Density at Room Temp (lbm/ft ³) kg/m ³	Temperature of Foam Sample									
	40°C		20°C		0°C		-20°C		-40°C	
	N1	N2	N1	N2	N1	N2	N1	N2	N1	N2
(11.9) 206.8										
(13.9) 231.4										
(15.9) 252.3										
(20.6) 274.8										
(22.6) 293.7										
(24) 326.0										

Compression Test Temperature/Density Matrix

Sample Identification: D__ T__ N__

Density of Sample
in lbm/ft³

Sample #1 or Sample #2

Temperature
of Sample

Note: Room Temp = 20°C

TABLE 2
Rigid Polyurethane Foam Compression Tests
Density and Crush Strength Data

	AREA	40% ϵ LOAD	DENSITY	CRUSH STRENGTH		AREA	40% ϵ LOAD	DENSITY	CRUSH STRENGTH
	mm ²	KN	kg/m ³	MPa		mm ²	KN	kg/m ³	MPa
TEST TEMPERATURE: 0 DEG. C					TEST TEMPERATURE: 20 DEG. C				
D11.9T0					D11.9T20				
N1	7182.6860	44.5100	215.4866	6.1968	N1	7182.6860	30.4000	198.8244	4.2324
N2	7171.2749	42.8400	213.8478	5.9738	N2	7186.4424	32.2000	215.5360	4.4807
D13.9T0					D13.9T20				
N1	7144.5820	50.2000	237.5342	7.0263	N1	7148.3286	37.6000	219.4433	5.2600
N2	7148.3286	51.7600	239.1132	7.2409	N2	7125.5679	47.0000	243.2496	6.5960
D15.9T0					D15.9T20				
N1	7140.8369	52.8400	248.1127	7.3997	N1	7117.9702	47.0000	251.2306	6.6030
N2	7144.5820	51.7600	245.2969	7.2447	N2	7136.9434	54.4000	262.1580	7.6223
D20.6T0					D20.6T20				
N1	7148.3286	74.6100	294.9181	10.4374	N1	7140.8369	50.4000	258.1739	7.0580
N2	7148.3286	65.7800	271.5162	9.2022	N2	7144.5820	59.0000	286.9137	8.2580
D22.6T0					D22.6T20				
N1	7217.1274	94.5100	330.1497	13.0952	N1	7220.8931	67.8000	297.4076	9.3894
N2	7209.4502	62.9400	261.0850	8.7302	N2	7209.4502	73.6000	306.1767	10.2088
D24T0					D24T20				
N1	7152.2251	110.2000	350.7861	15.4078	N1	7186.5034	77.5000	315.5247	10.7841
N2	7171.2749	106.4700	350.1115	14.8467	N2	7167.3726	95.0000	351.4563	13.2545
TEST TEMPERATURE: -20 DEG. C					TEST TEMPERATURE: 40 DEG. C				
D11.9T-20					D11.9T40				
N1	7186.4424	40.6900	204.8686	5.6621	N1	7133.0518	26.4000	204.4590	3.7011
N2	SAMPLE N2 DAMAGED, NOT TESTED				N2	7144.5820	31.2500	211.7515	4.3739
D13.9T-20					D13.9T40				
N1	7136.9434	58.3300	241.7113	8.1730	N1	7136.9434	36.9700	237.3326	5.1801
N2	7106.1313	51.6700	228.8721	7.2712	N2	7136.9434	32.9900	227.2503	4.6224
D15.9T-20					D15.9T40				
N1	7133.0518	68.8200	262.7127	9.6480	N1	7133.0518	40.7500	251.9198	5.7128
N2	7140.8369	52.9400	237.9410	7.4137	N2	7106.5796	38.8200	251.3524	5.4625
D22.6T-20					D20.6T40				
N1	7209.4502	95.6900	309.3654	13.2729	N1	7262.9756	46.1000	261.3273	6.3473
N2	7209.4502	81.1800	294.8009	11.2602	N2	7175.0283	44.6000	263.5827	6.2160
D24T-20					D22.6T40				
N1	7159.8716	110.0000	346.1671	15.3634	N1	7205.5376	40.3700	250.5867	5.6026
N2	7170.9746	85.1000	295.2521	11.8673	N2	7220.8931	48.6000	266.5138	6.7305
TEST TEMPERATURE: -40 DEG. C					D24T40				
D11.9T-40					N1	7182.6860	75.2100	337.7599	10.4710
N1	7171.2749	45.6700	194.6344	6.3685	N2	7140.8369	81.5000	345.4513	11.4132
N2	7182.6860	44.5100	202.2297	6.1968					
D13.9T-40									
N1	7144.5820	52.5500	222.9307	7.3552					
N2	7144.5820	49.6100	216.7448	6.9437					
D15.9T-40									
N1	7140.8369	72.0600	255.6627	10.0913					
N2	7182.6860	71.5700	256.2271	9.9642					
D20.6T-40									
N1	7163.6216	86.4700	288.3062	12.0707					
N2	7163.6216	78.4300	274.0101	10.9484					
D22.6T-40									
N1	7217.1274	100.3900	300.1661	13.9100					
N2	7220.8931	108.2400	321.0273	14.9898					
D24T-40									
N1	7182.6860	110.0000	327.3247	15.3146					
N2	7175.0283	60.5900	239.8971	8.4446					

TABLE 3

Comparison of Sample Densities: Variation from Average Values

Manufacturer's Predicted Density kg/m ³ (lb/ft ³)	Average Density kg/m ³	Percent Difference Actual:Predicted	Max. Density of Samples kg/m ³	Min. Density of Samples kg/m ³	Avg. % Difference of Samples from Mean Density	Maximum % Difference of Samples from Mean Density
190.6 (11.9)	206.8	+ 8%	215.5	194.6	8.5%	13%
227.7 (13.9)	231.4	+ 4%	243.3	216.7	4%	9%
254.7 (15.9)	252.3	+ 1%	262.7	237.9	1%	7%
330.0 (20.6)	274.8	-17%	294.9	258.1	17%	22%
362.0 (22.6)	293.7	-19%	330.1	261.1	19%	28%
384.4 (24.0)	326.0	-18%	351.5	239.9	15%	38%

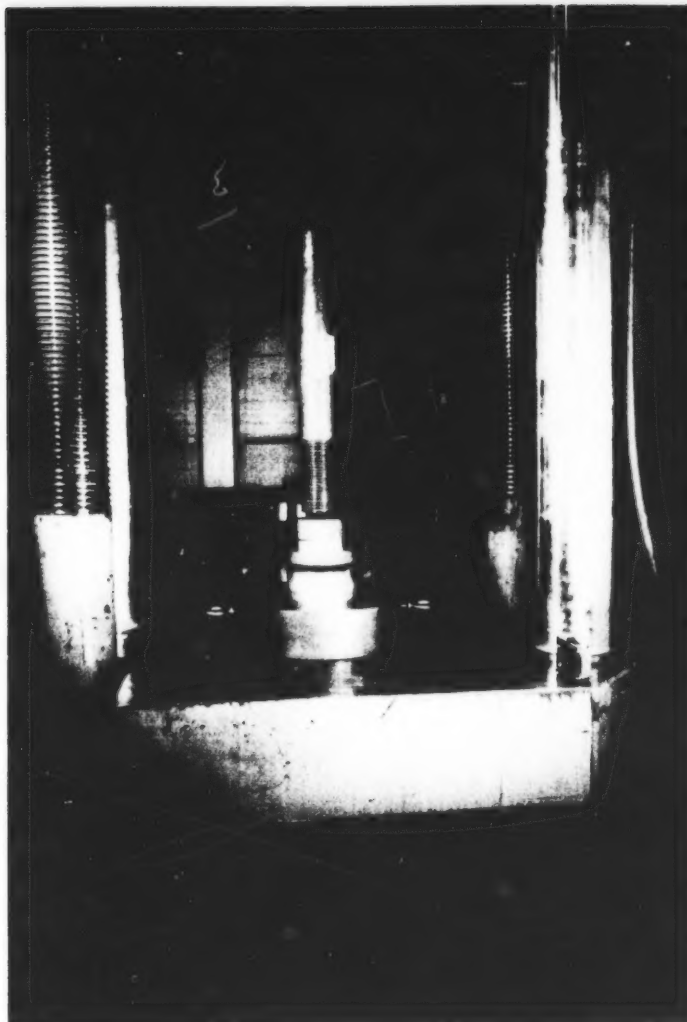


FIGURE 1
COMPRESSION TEST APPARATUS FOR ROOM TEMPERATURE TESTS
(600,000 lb BALDWIN UNIVERSAL TEST MACHINE)

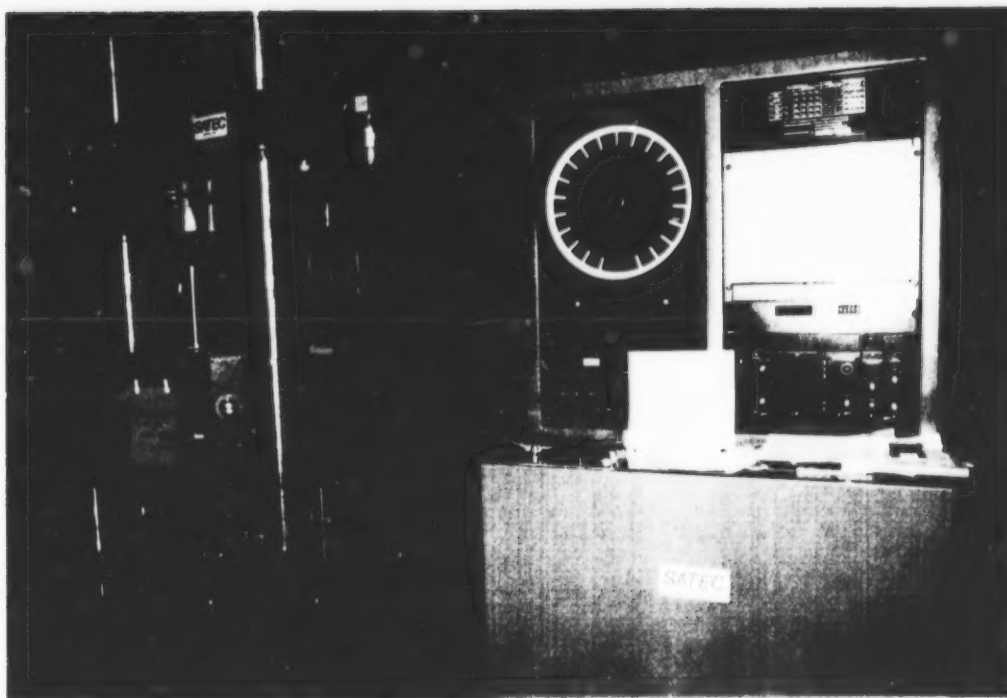


FIGURE 2
COMPRESSION TEST APPARATUS FOR -40°C, -20°C, 0°C AND +40°C
TESTS. (120,000 lb. BALDWIN UNIVERSAL TEST MACHINE.)

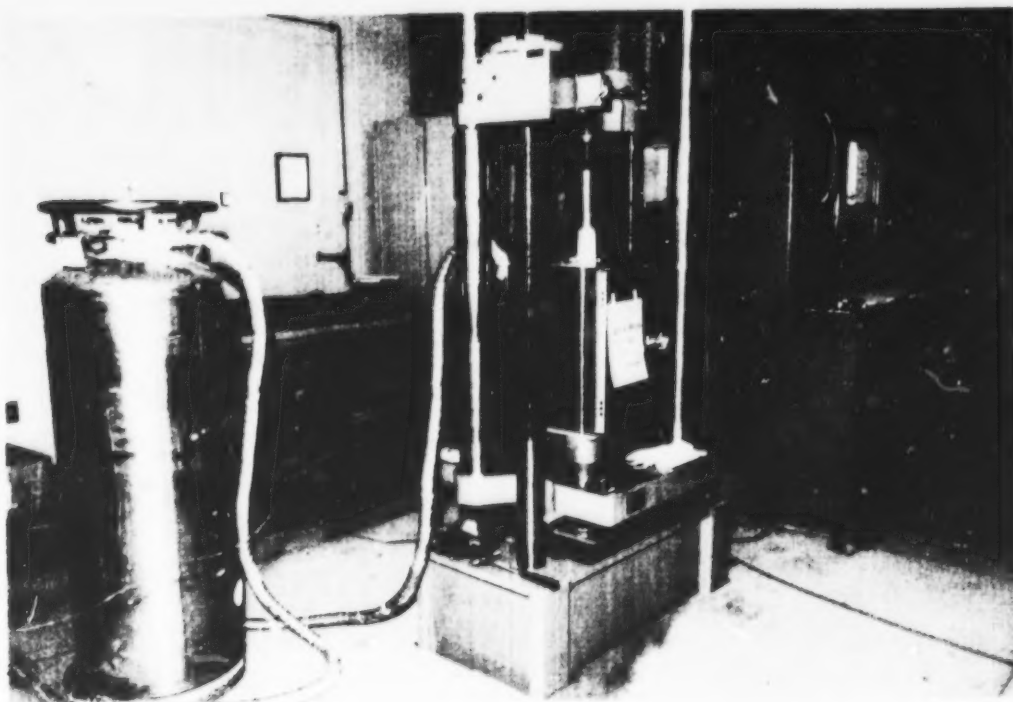


FIGURE 3
COLD TEMPERATURE TESTS, TEST EQUIPMENT

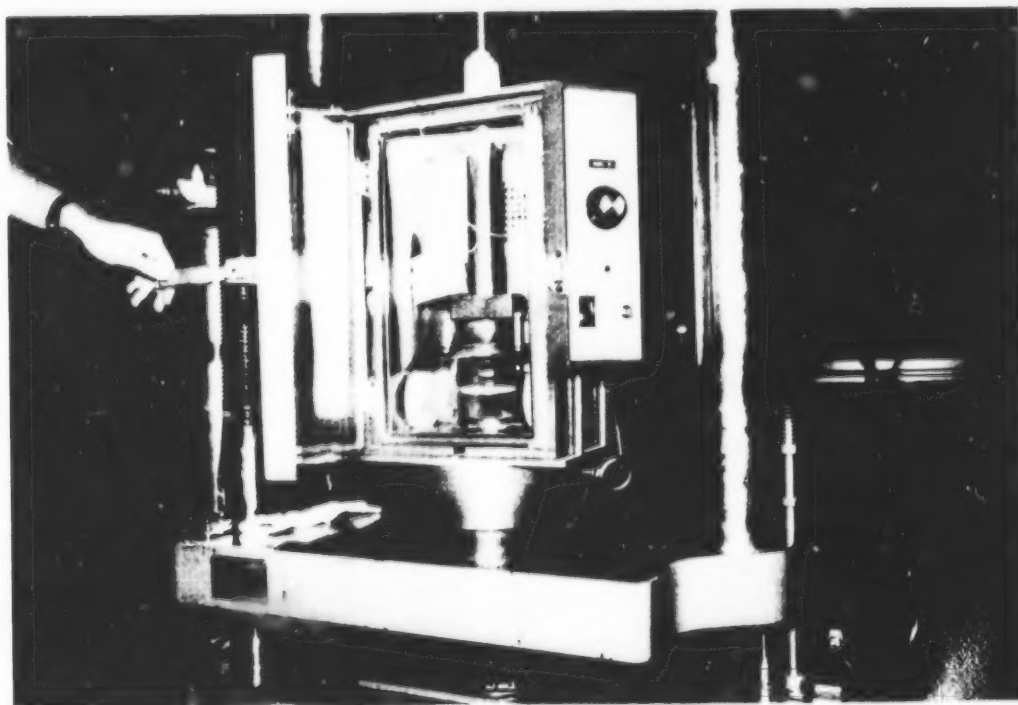


FIGURE 4
COLD TEMPERATURE TEST, INTERNAL
COMPONENTS OF TEST APPARATUS

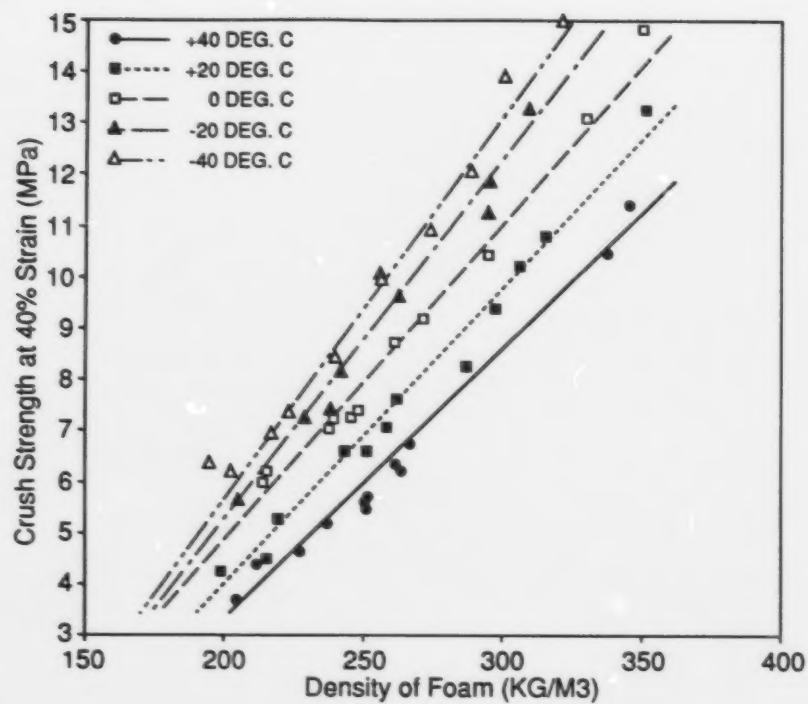
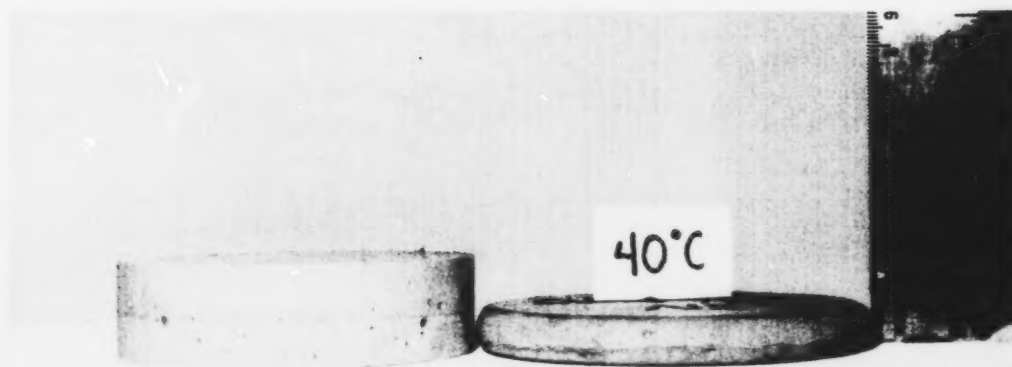
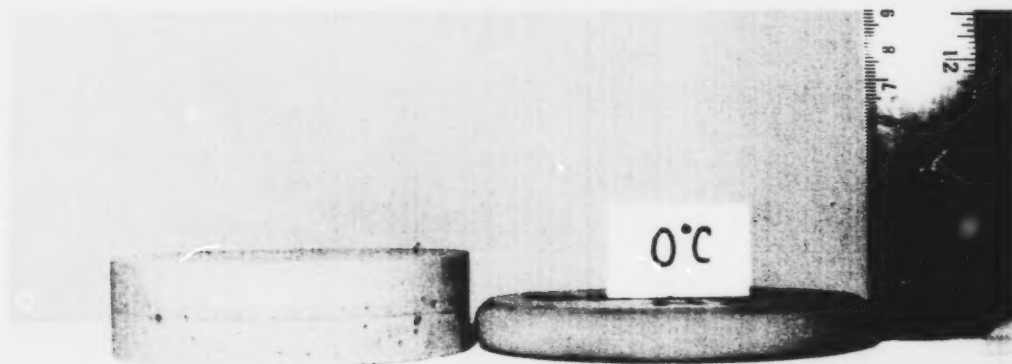


FIGURE 5
CRUSH STRENGTH AT 40% ϵ
PLOTTED AGAINST SAMPLE DENSITY
FOR 5 TEST TEMPERATURES

a)



b)



c)

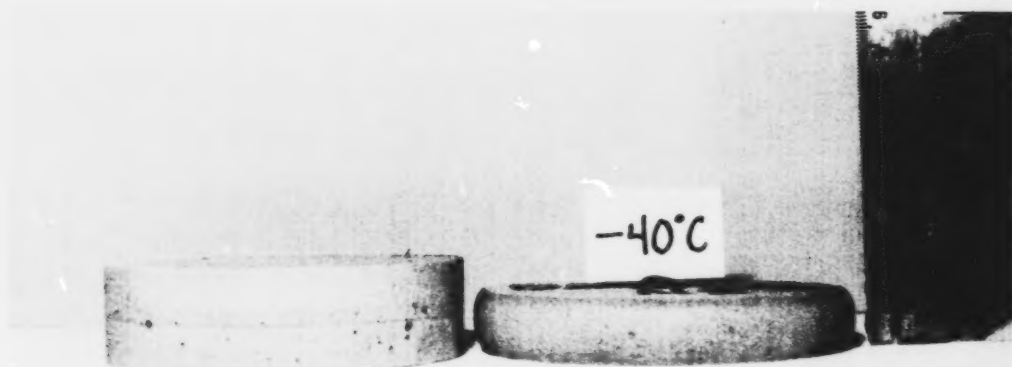


FIGURE 6
STRAIN RECOVERY IN COMPRESSION SAMPLES

- a) TESTED AT 40°C
- b) TESTED AT 0°C
- c) TESTED AT -40°C

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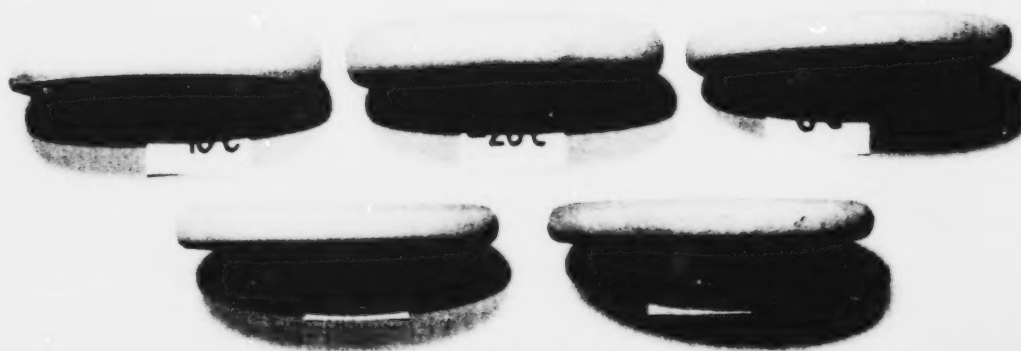


FIGURE 7
STRAIN RECOVER IN SAME NOMINAL DENSITY SAMPLES
TESTED AT 40°C, 20°C, 0°C, -20°C AND -40°C

APPENDIX A
DERIVATION OF FOAM CRUSH STRENGTH MODEL

Appendix A

Derivation of Foam Crush Strength Model

1.0 DESCRIPTION OF PROCEDURE

The plot of 40% crush strength as a function of foam density (Figure 5, main body) indicates that a linear approximation of the relationship provides a good representation of the data.

Linear regression was performed on results from each temperature leading to the following equations:

$$\text{General form:} \quad S_{\text{crush}} = m \times R_o + b \quad (1)$$

$$+40^{\circ}\text{C:} \quad S_{\text{crush}} = 5.328 \times 10^{-2} \times R_o - 7.49 \quad (2)$$

$$+20^{\circ}\text{C:} \quad S_{\text{crush}} = 5.900 \times 10^{-2} \times R_o - 7.95 \quad (3)$$

$$+0^{\circ}\text{C:} \quad S_{\text{crush}} = 6.745 \times 10^{-2} \times R_o - 8.92 \quad (4)$$

$$-20^{\circ}\text{C:} \quad S_{\text{crush}} = 7.015 \times 10^{-2} \times R_o - 8.88 \quad (5)$$

$$-40^{\circ}\text{C:} \quad S_{\text{crush}} = 7.286 \times 10^{-2} \times R_o - 8.59 \quad (6)$$

It is obvious that these equations vary with temperature. The slope 'm' was then plotted against absolute temperature to give an indication of the relationship, Figure 1. After reviewing the shape of this data, a second linear regression was used to approximate the function $m(T)$. This is also shown in Figure 1 and has the form:

$$m = -2.5155 \times 10^{-4} \times T + 0.13322 \quad (7)$$

In the same manner, the intercept 'b' of equation (1) was plotted against absolute temperature (Figure 2). A quadratic function was developed using a least squares fit approximation and the result is plotted in Figure 2. The equation of this function is:

$$b = 4.8394 \times 10^{-4} \times T^2 - 0.2486 \times T + 23.051 \quad (8)$$

Combining Equations (1), (7) and (8) results in a function describing the crush strength of foam at 40% strain when given density and temperature data:

$$S_{\text{crush}} = (-2.5155 \times 10^{-4} \times T + 0.13322) \times R_o \\ + (4.8394 \times 10^{-4} \times T^2 - 0.2486 \times T + 23.051) \quad (9)$$

$$\begin{aligned} S_{\text{crush}} &= \text{Crush strength at 40\% strain (MPa)} \\ R_o &= \text{Density (kg/m}^3\text{)} \\ T &= \text{Temperature (K)} \end{aligned}$$

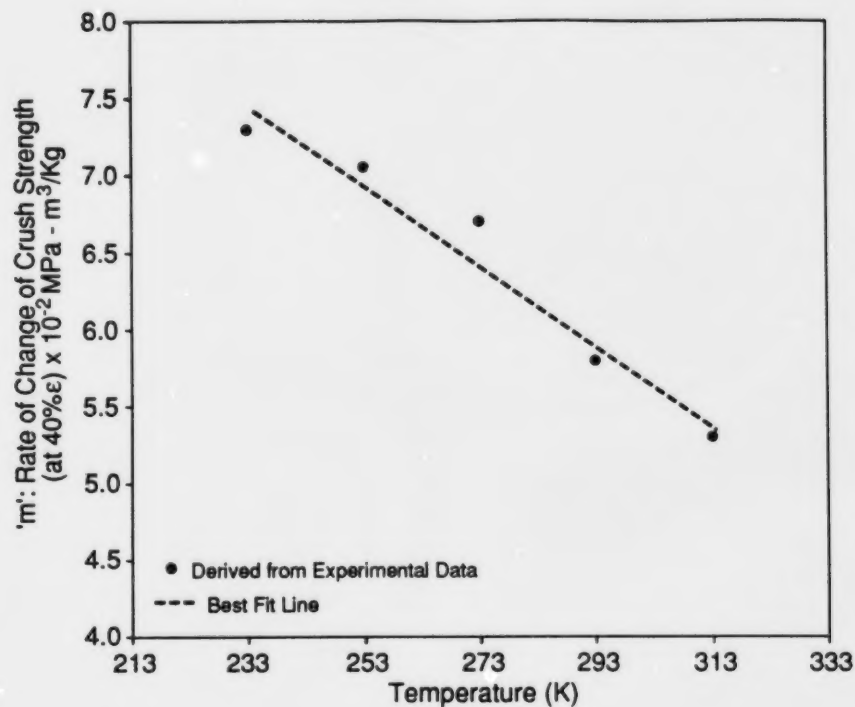


FIGURE A-1
SLOPE OF EQUATIONS 2, 3, 4, 5 AND 6
AS A FUNCTION OF TEMPERATURE

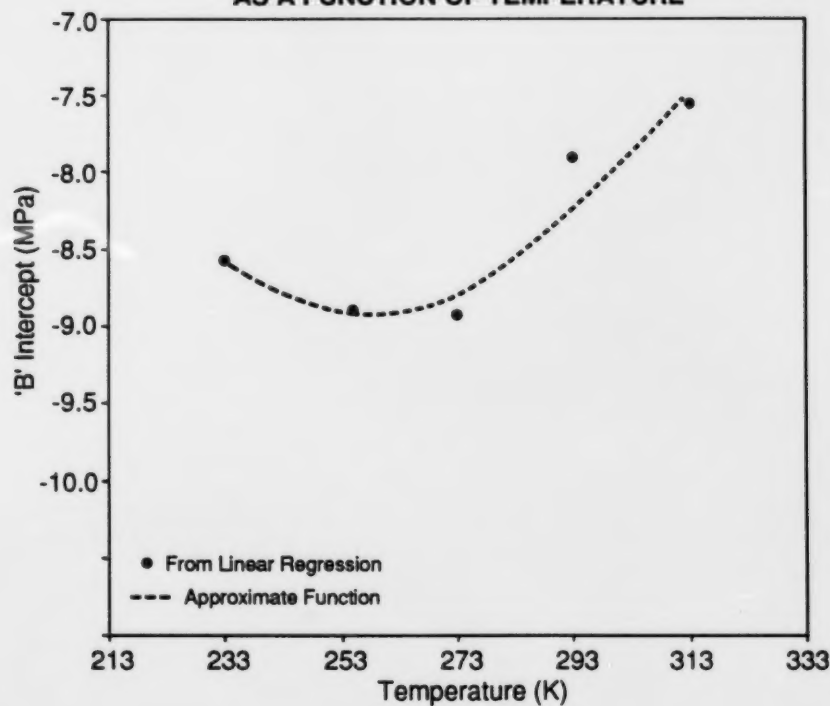
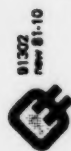


FIGURE A-2
INTERCEPTS OF EQUATIONS 2, 3, 4, 5 AND 6
AS A FUNCTION OF TEMPERATURE

APPENDIX B
EXPERIMENTAL DATA



91302
Rev 81-10

to

research division - examination and tests of material

material submitted by S. Reid		date submitted	
job 21-278-	file	report number 8689- -H	
material description		remarks	
item 1	quantity 60	type and dimensions Nominal dimensions: lucithic x 3750 in dia	Remarks Perform compression tests on submitted foam samples at temperatures of 40, 20, 0, -20 and -40 °C.
observations The sixty samples of rigid polyurethane foam consisted of five separate densities; 191, 223, 255, 330, 362 and 384 kg/m³. Two samples from each density were to be tested at each test temperature. Before testing the specimen dimensions and weight were recorded (Table 1) and each sample was labeled with its particular density, test temperature and sample number. A strain rate of .65 in/in/min was used and each sample to be compressed 65% of its original thickness. A shear/strain curve was required. Samples were loaded in a 600,000 LB universal test machine. (Fig 1) After completion of the tests at room temperature it was observed that the resultant loads were not as high as originally anticipated. Therefore all remaining tests were conducted in a 120,000 LB universal test machine. A strain extension and compression equipped with fixtures was used to handle the test for the elevated temperature tests. The same chamber was used for temperature tests using liquid nitrogen as the refrigerant. (Fig 2) After analyzing the test results from the room temperature tests it was determined by the test engineer to compress only the remaining samples to 75% of its original thickness. A stress/strain curve was also produced representative of the actual stiffness of the test setup and each machine that was used for loading. (Fig 3 & 4)			
signature		author's signature	
signature <i>Susan Reid</i>		signature D. G. A	
approvals		date approved April 13, 1989	
		title	

FIGURE B-1

TEST OF MATERIAL REPORT: SUBMITTED BY MECHANICAL TEST SECTION, CONTAINING A DESCRIPTION OF WORK DONE AND OBSERVATIONS OF TEST

TABLE B-1

Sample No.	Weight (grams)	Orig. Thickness (inch)	Orig. Diameter (inch)	Final Thickness (inch)	Final Diameter (inch)
D191T40N1	37.229	1.005	3.752	0.432	4.055
D191T40N2	38.657	1.006	3.755	0.419	4.025
D191T20N1	36.672	1.011	3.765	0.487	4.058
D191T20N2	39.501	1.004	3.766	0.480	4.069
D191T0N1	39.680	1.005	3.765	0.422	3.986
D191T0N2	39.069	1.003	3.762	0.415	4.000
D191T-20N1	37.546	1.004	3.766	0.475	4.100
D191T-20N2	36.849	1.005	3.764	*	—
D191T-40N1	35.630	1.005	3.762	*	—
D191T-40N2	37.043	1.004	3.765	0.510	4.050
D223T40N1	43.152	1.003	3.753	0.408	4.012
D223T40N2	41.361	1.004	3.753	0.403	4.060
D223T20N1	39.963	1.003	3.756	0.468	4.075
D223T20N2	44.114	1.002	3.756	0.445	4.024
D223T0N1	43.279	1.004	3.755	0.424	4.022
D223T0N2	43.675	1.006	3.756	0.411	4.024
D223T-20N1	43.905	1.002	3.753	0.430	4.053
D223T-20N2	41.517	1.005	3.748	0.424	4.061
D223T-40N1	40.537	1.002	3.755	0.450	4.011
D223T-40N2	39.869	1.003	3.755	0.470	4.022
D255T40N1	45.026	1.004	3.752	0.412	4.022
D255T40N2	45.462	1.002	3.745	0.418	4.060
D255T20N1	45.604	1.004	3.748	0.461	4.088
D255T20N2	47.619	1.002	3.753	0.449	4.044
D255T0N1	45.227	1.005	3.754	0.412	4.101
D255T0N2	44.781	1.006	3.755	0.412	4.115
D255T-20N1	47.883	1.006	3.752	0.429	4.075
D255T-20N2	43.502	1.008	3.754	0.425	4.110
D255T-40N1	46.742	1.008	3.754	0.475	4.045
D255T-40N2	46.886	1.003	3.756	0.460	4.025

TABLE B-1 (CONTINUED)

D320T40N1		48.257	1.001	3.786	0.417	4.058
D320T40N2		48.277	1.005	3.763	0.427	4.090
D320T20N1		47.061	1.005	3.754	0.475	4.077
D320T20N2		52.276	1.004	3.755	0.475	4.090
L320T0N1		53.258	1.006	3.756	0.438	4.122
L320T0N2		49.644	1.007	3.756	0.455	4.015
L320T20N1		54.044	1.005	3.755	0.443	4.121
L320T20N2		50.932	1.002	3.759	0.443	4.043
L320T40N1		52.616	1.003	3.760	0.462	4.136
L320T40N2		50.058	1.004	3.760	0.463	4.059
D362T40N1		46.137	1.006	3.771	0.431	4.087
D362T40N2		49.174	1.006	3.775	0.427	4.120
D362T20N1		54.930	1.007	3.775	0.437	4.116
D362T20N2		56.460	1.007	3.772	0.444	4.080
D362T0N1		60.821	1.005	3.774	0.422	4.170
D362T0N2		48.016	1.006	3.772	0.429	4.105
D362T20N1		57.048	1.007	3.772	0.460	4.126
D362T20N2		54.217	1.006	3.777	0.425	4.170
D362T40N1		54.214	0.996	3.774	0.455	4.112
D362T40N2		59.056	1.003	3.775	* —	—
D384T40N1		61.621	1.000	3.765	0.431	4.109
D384T40N2		65.657	1.000	3.754	0.448	4.121
D384T20N1		57.595	1.000	3.766	0.437	4.104
D384T20N2		64.240	1.004	3.761	0.455	4.165
L384T0N1		63.982	1.004	3.757	0.431	4.207
D384T0N2		63.901	1.002	3.762	0.415	4.208
L384T20N1		63.207	1.004	3.759	0.500	4.100
L384T20N2		53.866	1.002	3.761	0.417	4.150
D384T40N1		59.457	1.004	3.765	0.455	4.095
D384T40N2		43.808	1.002	3.763	0.470	4.070
* : Samples were loaded off centre.						

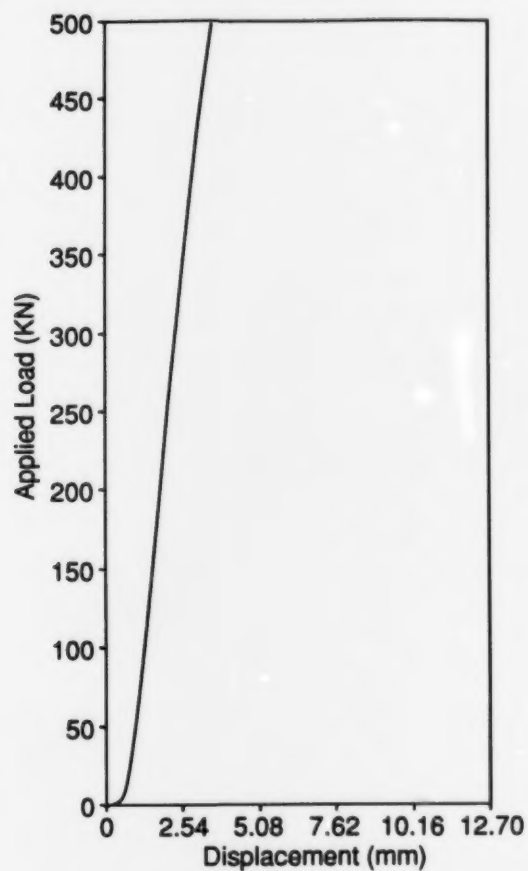


FIGURE B-2
MACHINE STIFFNESS
TEST SETUP STIFFNESS FOR FOAM SAMPLES
IN 120,000 lb BALDWIN UNIVERSAL TEST MACHINE

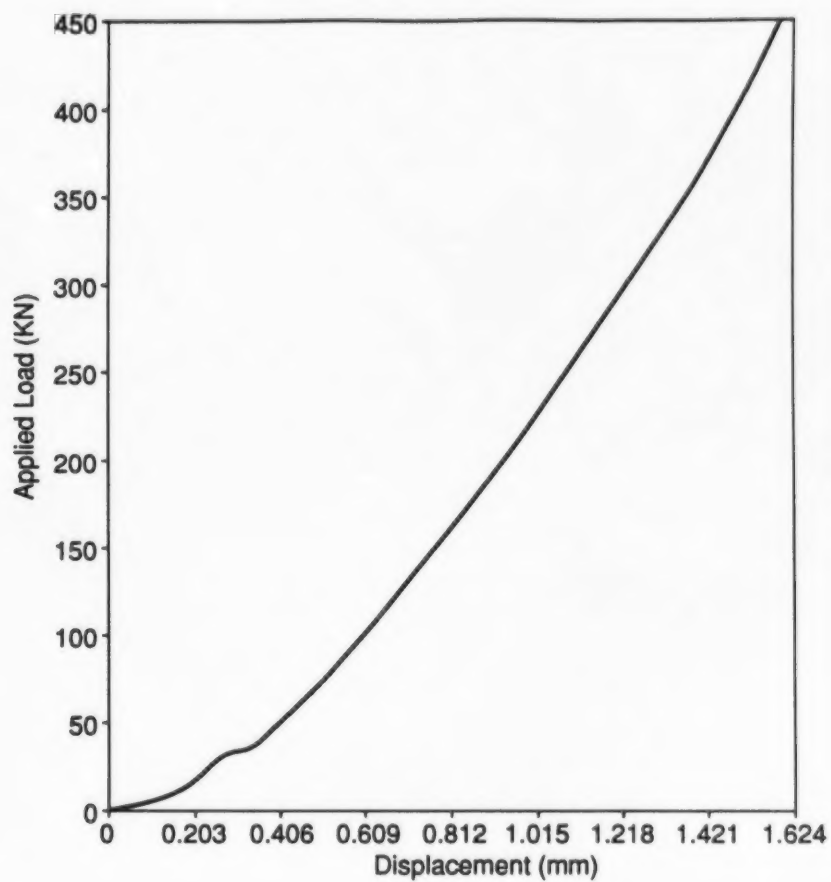


FIGURE B-3
MACHINE STIFFNESS
TEST SETUP STIFFNESS FOR FOAM SAMPLES
IN 600,000 lb BALDWIN UNIVERSAL TEST MACHINE

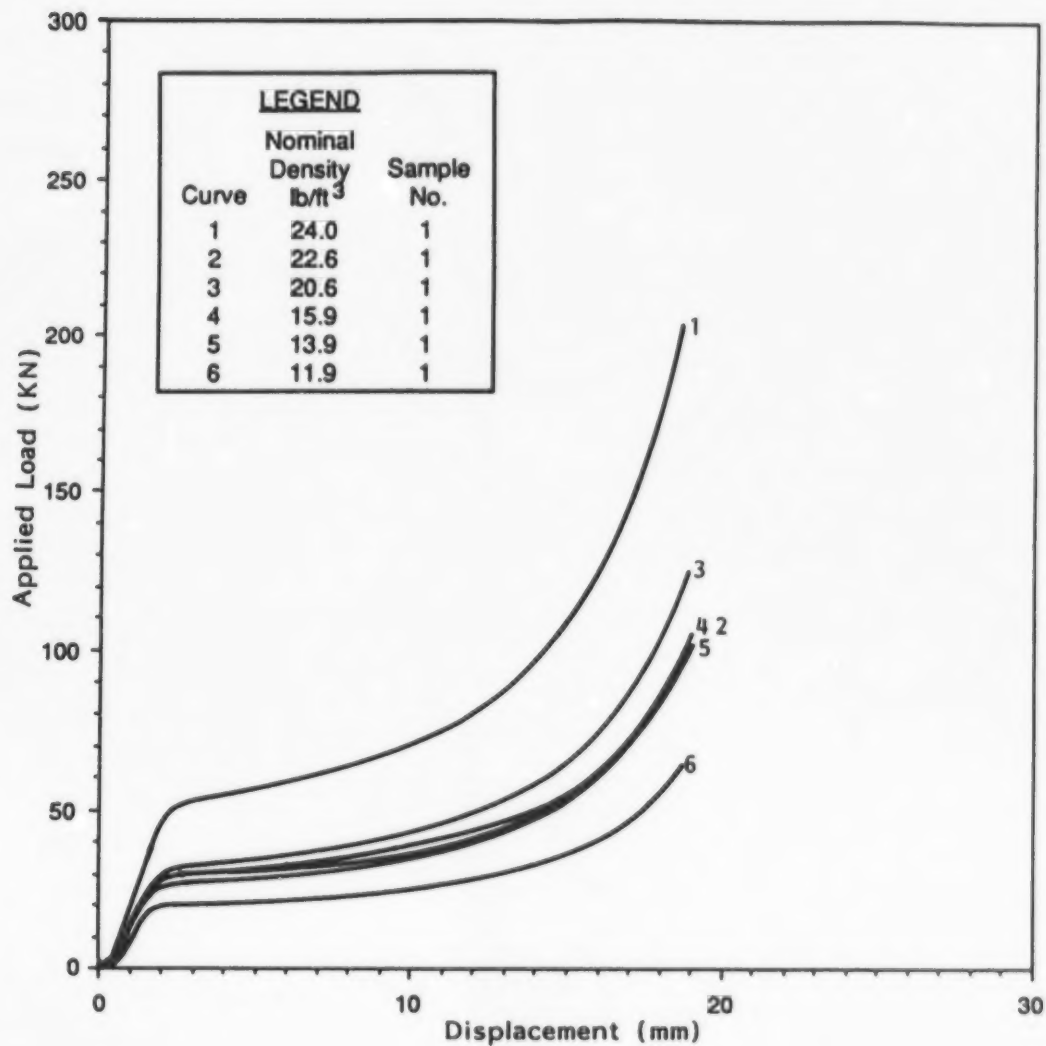


FIGURE B-4
LOAD DISPLACEMENT CURVE OF SAMPLE 1, ALL
DENSITIES AT 40°C

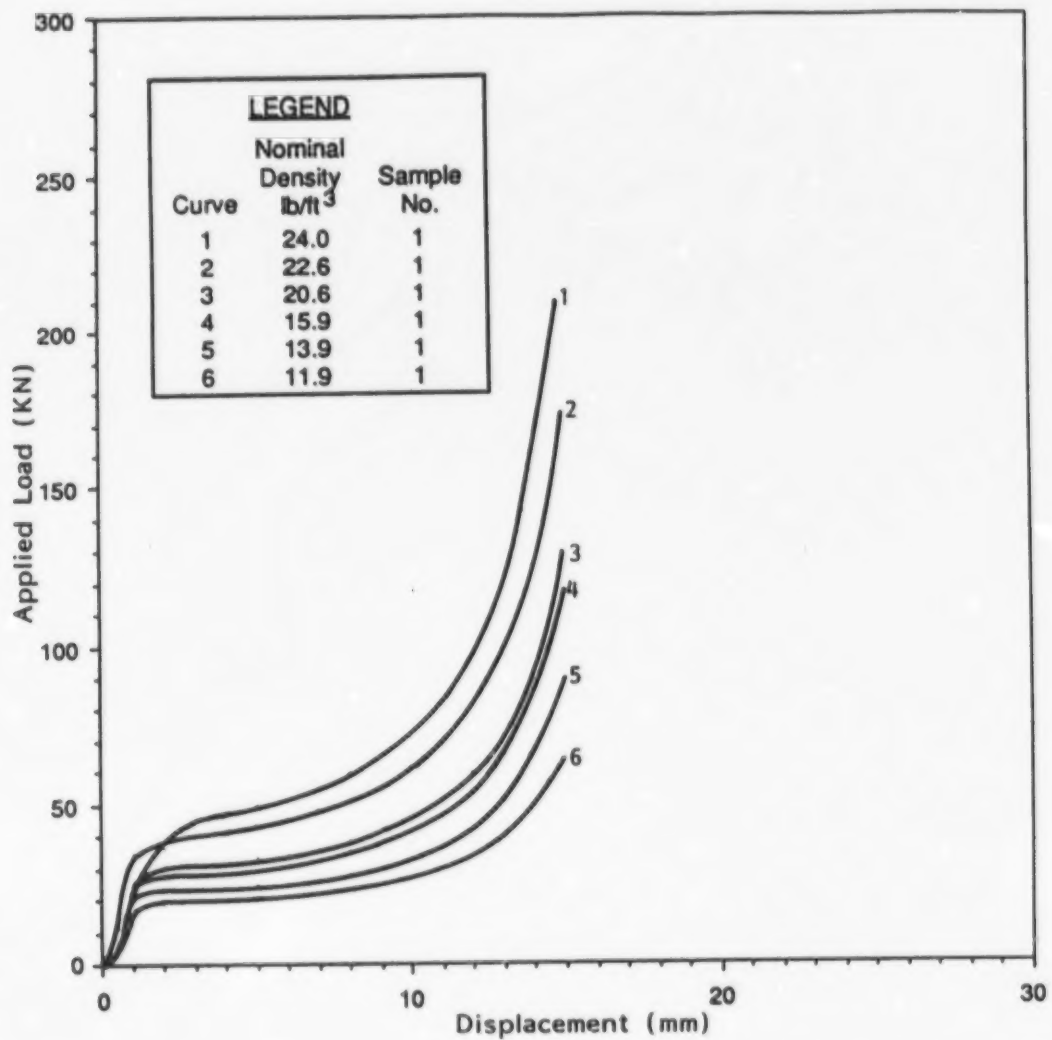


FIGURE B-5
LOAD DISPLACEMENT CURVE OF SAMPLE 1, ALL
DENSITIES AT 20°C

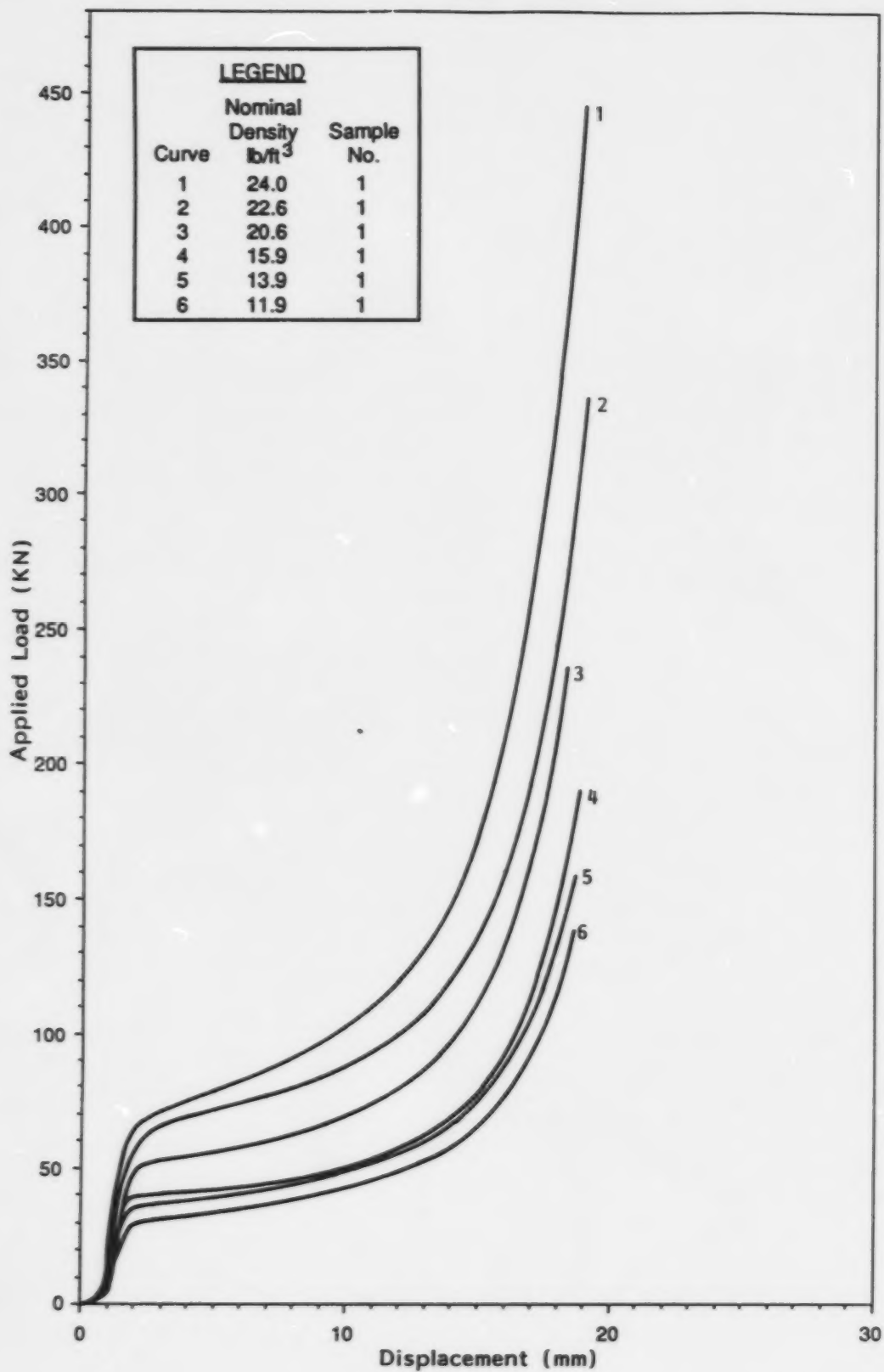


FIGURE B-6
LOAD DISPLACEMENT CURVE OF SAMPLE 1, ALL
DENSITIES AT 0°C

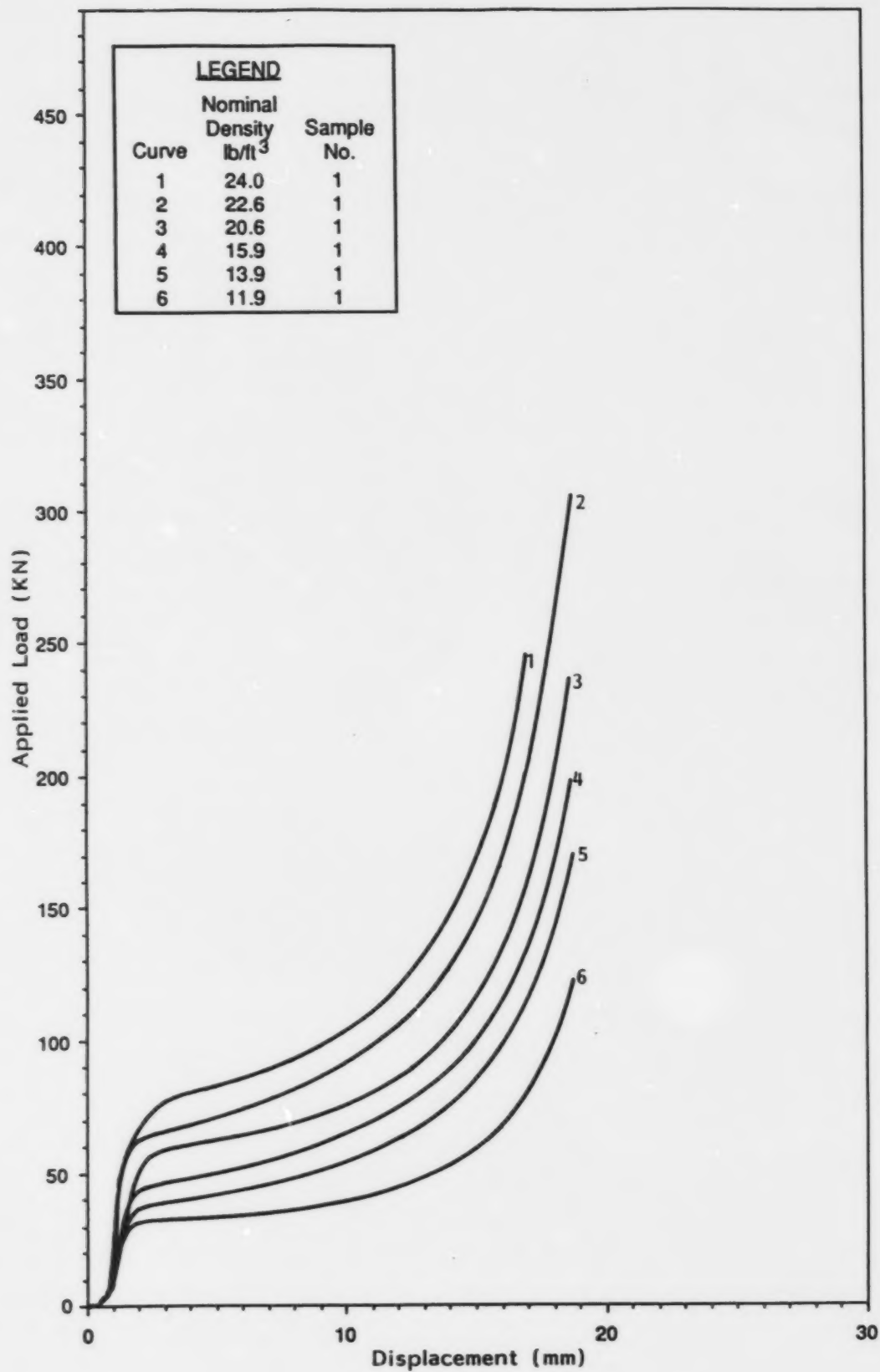


FIGURE B-7
LOAD DISPLACEMENT CURVE OF SAMPLE 1, ALL
DENSITIES AT -20°C

179913-RD

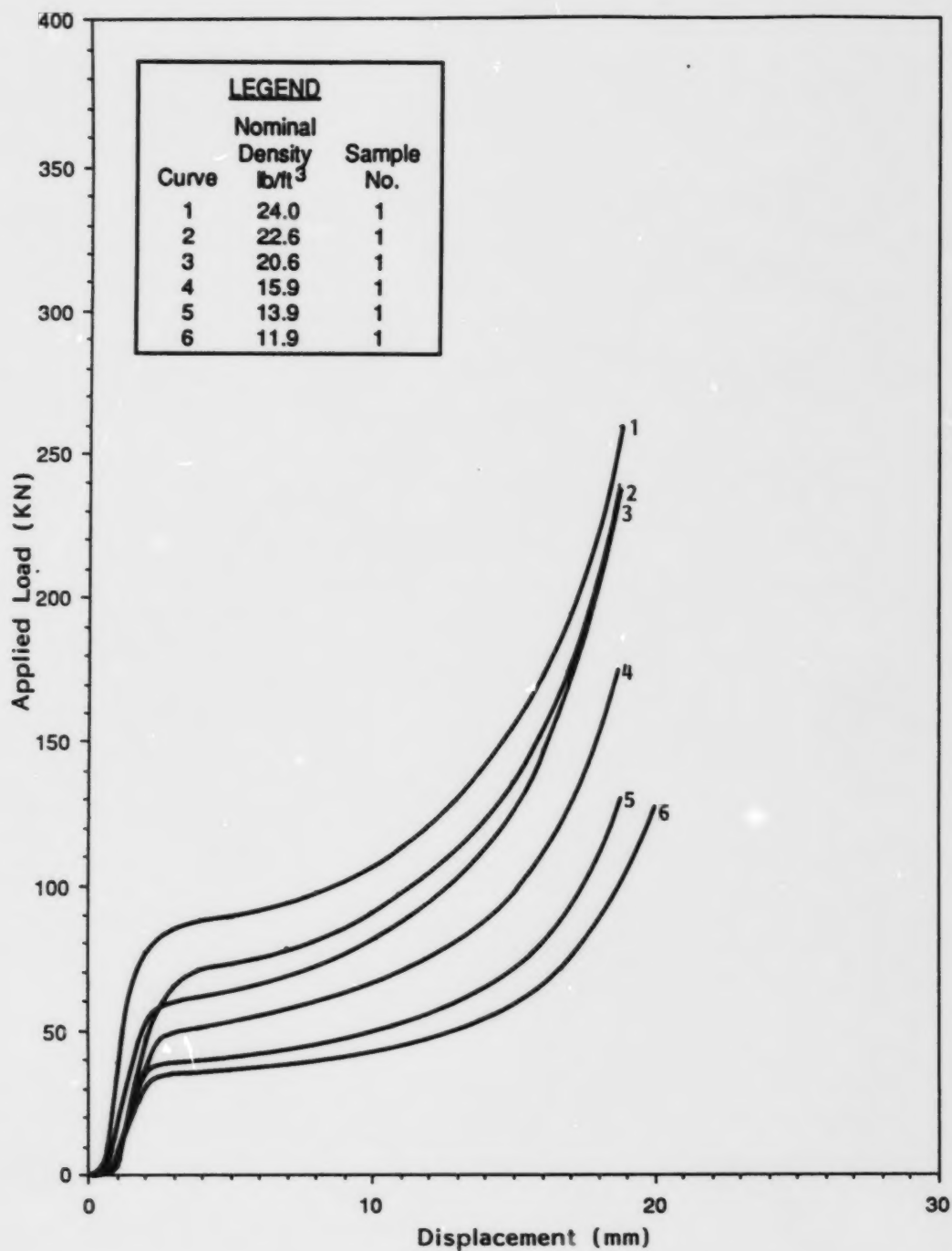


FIGURE B-8
LOAD DISPLACEMENT CURVE OF SAMPLE 1, ALL
DENSITIES AT -40°C